RTCA Free Flight Select Committee
Safe Flight 21 Steering Committee

Eurocontrol ADS Programme

ADS-B Technical Link Assessment Team (TLAT)

Technical Link Assessment Report

March 2001

APPENDIX K - Attachment 4

VDL Mode 4 Simulation Results
Eurocontrol Exp. Centre

Slide 1

This is a presentation of the results of the VDL-4 simulations conducted by Eurocontrol. The Eurocontrol simulation effort is ongoing, and this presentation will be updated with new simulation results as they are produced.
A separate report (MS Word document) is also available with the complete set of results.

Slide 2

Contents

- Approach
- Traffic Scenarios and Assumptions
- Individual channel simulations
  - GSC
  - RSC
- Multi-Channel Simulations
- Antenna Gain Model
- Entry in Region
- Conclusions and remaining open issues

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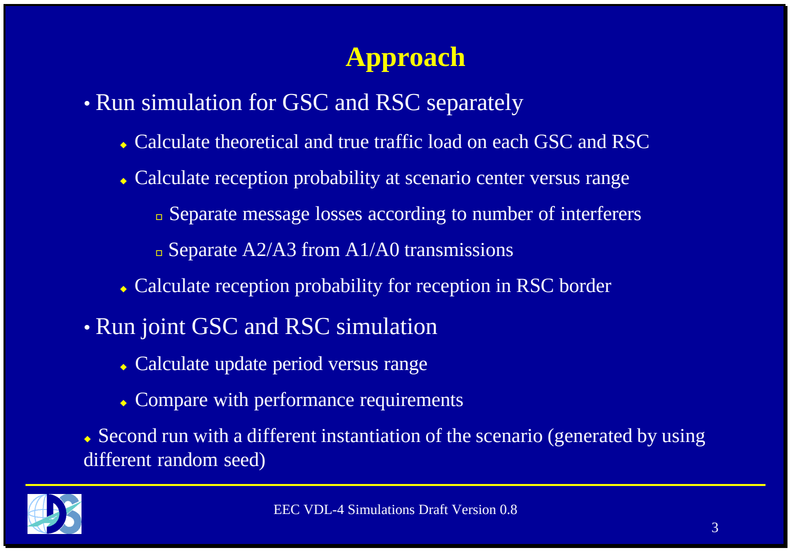
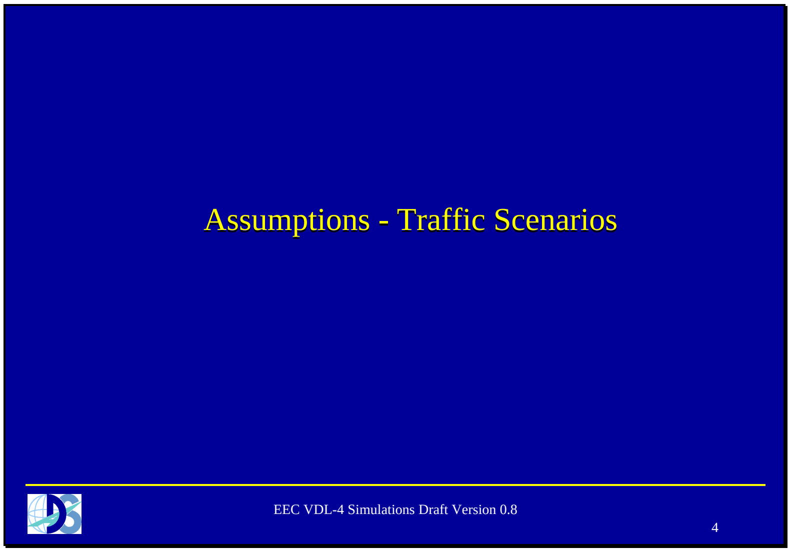
Slide 3



Performance is measured performance with regard to an observation point (=victim receiver) located at Brussels center (= scenario center), and for different altitudes. Performance has also been measured as average reception probability for all receivers within x nmi of the scenario center (up to x=100 nmi).

Slide 4


Assumptions - Traffic Scenarios
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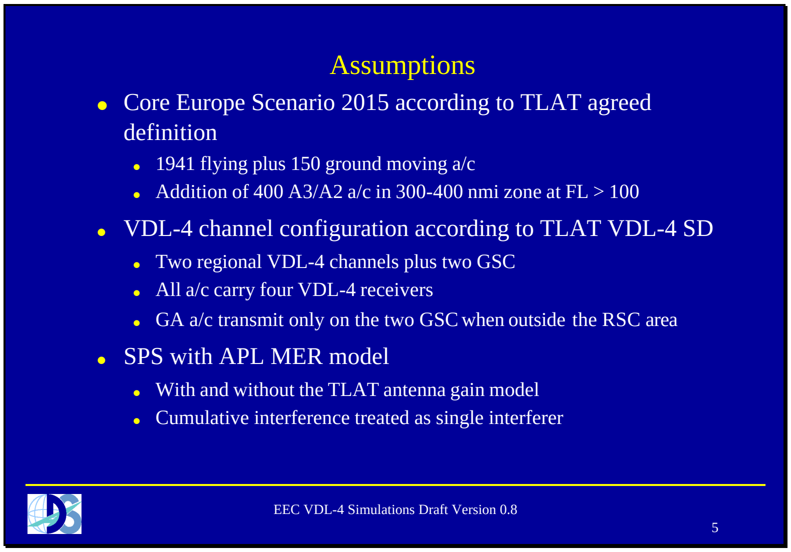
Slide 5



In accordance with the TLAT VDL-4 System Description, GA a/c outside the RSC transmit at the fixed rate of 6 msg/min irrespectively of airspace.
Ground moving a/c transmit in a separate local channel (not simulated) but also in the GSC. They have therefore been included in the GSC simulations.
Performance has been calculated by analysing the log produced by SPS. The SPS log records (among other things) each message transmitted and its reception status for each station in the scenario.

Slide 6

Region		Description	A/C Density	No of a/c
Core en-route		Traffic density per unit area	0.00554	(total 696)
		Proportion of traffic in alt. Band L	6%	42
		Proportion of traffic in alt. Band M	16%	111
		Proportion of traffic in alt. Band H	39%	271
		Proportion of traffic in alt. Band U	39%	272
Core TMA (N=0-4)	Inner	Inner Traffic density per unit area	0.0641	(total 29 per TMA)
		Proportion of traffic in alt. Band L	65%	19
		Proportion of traffic in alt. Band M	35%	10
	Outer	Outer Traffic density per unit area	0.0131	(total 103 per TMA)
		Proportion of traffic in alt. Band M	35%	36
		Proportion of traffic in alt. Band H	65%	67
Non-core en-route		Traffic density per unit area	0.00277	(total 435)
		Proportion of traffic in alt. Band L	6%	26
		Proportion of traffic in alt. Band M	16%	70
		Proportion of traffic in alt. Band H	39%	170
		Proportion of traffic in alt. Band U	39%	169
Non-core TMA		Terminal traffic density (non-core) per unit area	0.000955	(total 150)
		Proportion of traffic in altitude band L	50%	75
		Proportion of traffic in altitude band M	30%	45
		Proportion of traffic in altitude band H	20%	30
Ground	Entire scenario	Density of moving aircraft traffic on surface over whole scenario	8.84×10^{-5}	(total 25 over sce-nario)
	Core TMA (N=0-4)	Density of moving aircraft traffic on surface in each core TMA	0.318	(total 25 per TMA)

Traffic Distribution

A/C types allocated A0 to A3 as 10/30/30/30%

- A0 aircraft are kept below FL 100
- A1 aircraft are kept below FL 250
- GA a/c are 50% of A0 and A1

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Traffic densities have been specified in a Eurocontrol document defining the Core Europe 2015 scenario. The allocation 10:30:30:30 for equipment classes was proposed by Eurocontrol to the TLAT.

Initially it had been agreed to put all A0 and A1 aircraft below Fl 100, but there are not enough positions under FL100 to do so. To overcome this problem, Eurocontrol has proposed the allocation rules stated in the slide.

Slide 7

Aircraft Class Distribution

Region	Alt Band	Total	A0	A1	A2	A3	GA
Core En-Route	L	42	20	20	1	1	20
	M	111	50	55	3	3	53
	H	271	0	133	70	68	67
	U	272	0	0	136	136	0
Total		*696*	*70*	*208*	*210*	*208*	*140*
Core TMA Inner	L	19	2	5	6	6	4
(N=0-4)	M	10	1	4	2	3	2
Total		*29*	*3*	*9*	*8*	*9*	*6*
Core TMA Outer	M	36	10	8	9	9	9
(N=0-4)	H	67	0	23	22	22	11
Total		*103*	*10*	*31*	*31*	*31*	*20*
Non-Core En-Route	L	26	13	4	5	4	9
	M	70	31	34	3	2	33
	H	170	0	91	39	40	46
	U	169	0	0	84	85	0
Total		*435*	*44*	*129*	*131*	*131*	*88*
Non-Core TMA	L	75	9	22	22	22	15
	M	45	6	14	13	12	10
	H	30	0	9	11	10	5
Total		*150*	*15*	*45*	*46*	*44*	*30*
TOTAL		**1941**	**194**	**582**	**582**	**583**	**388**

Altitude Band	FL	Number of Aircraft	A0	A1	A2	A3	GA
G	0	150	15	45	45	45	30
L	0-30	238	52	71	58	57	64
M	30-100	456	142	163	74	77	151
H	100-250	806	0	348	230	228	173
U	250-410	441	0	0	220	221	0
Total		**2091**	**209**	**627**	**627**	**628**	**418**

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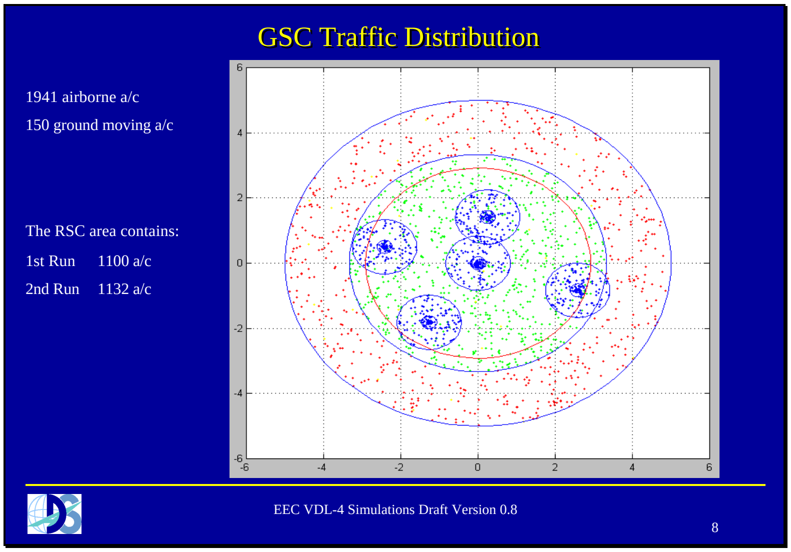
These tables have been derived from the tables of slide 4 applying the rules stated there.
These tables hold for both scenario instantiations run.

Slide 8



This figure shows the aircraft placement in the first run. It was obtained by a random application of the CE2015 scenario rules. The scenario has in total 1941 airborne and 150 ground moving a/c.

One dot is plotted for each aircraft.

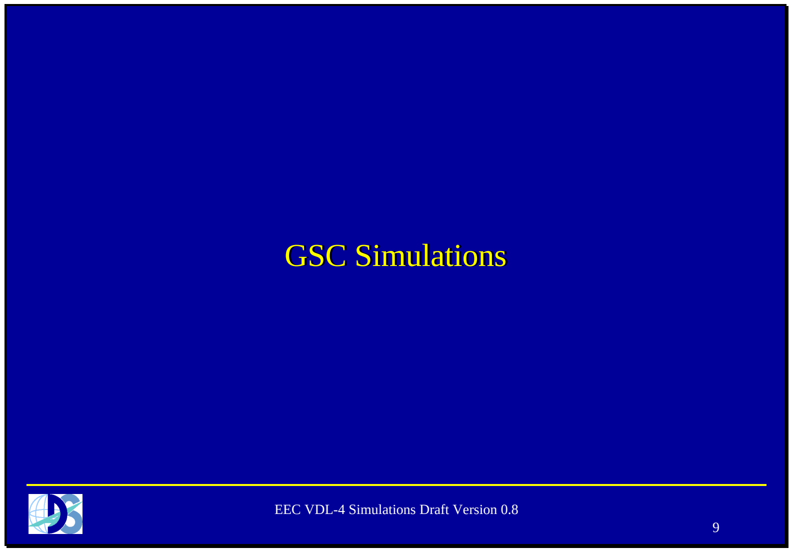
The blue circles indicate the five main TMAs.

The red circle shows the boundaries of the RSC area (radius = 175 nmi).

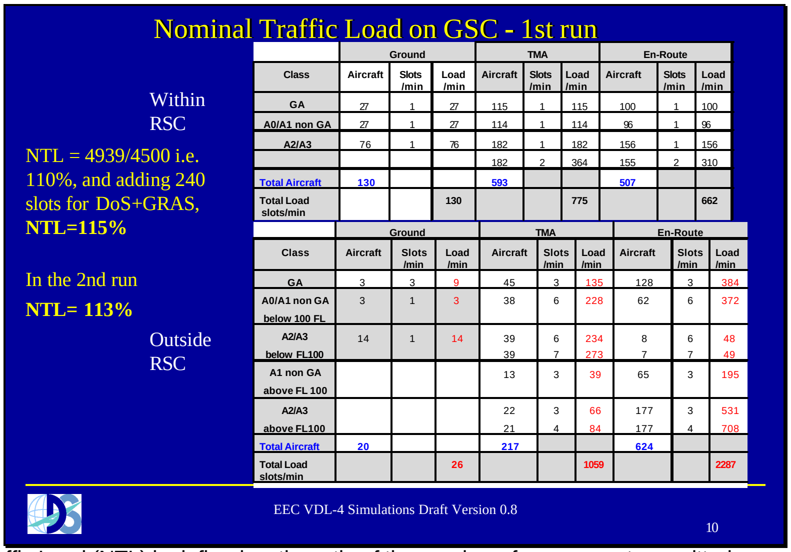
It has been agreed to apply the 175 nmi boundary for RSC irrespectively of TMA boundaries.

A second scenario has been produced with a different random seed from the same scenario rules. It contains the same number of aircraft as the first scenario.

Slide 9



Slide 10



	Ground			TMA			En-Route		
Class	Aircraft	Slots /min	Load /min	Aircraft	Slots /min	Load /min	Aircraft	Slots /min	Load /min
GA	27	1	27	115	1	115	100	1	100
A0/A1 non GA	27	1	27	114	1	114	96	1	96
A2/A3	76	1	76	182	1	182	156	1	156
				182	2	364	155	2	310
Total Aircraft	130			593			507		
Total Load slots/min			130			775			662

	Ground			TMA			En-Route		
Class	Aircraft	Slots /min	Load /min	Aircraft	Slots /min	Load /min	Aircraft	Slots /min	Load /min
GA	3	3	9	45	3	135	128	3	384
A0/A1 non GA below 100 FL	3	1	3	38	6	228	62	6	372
A2/A3 below FL100	14	1	14	39 39	6 7	234 273	8 7	6 7	48 49
A1 non GA above FL 100				13	3	39	65	3	195
A2/A3 above FL100				22 21	3 4	66 84	177 177	3 4	531 708
Total Aircraft	20			217			624		
Total Load slots/min			26			1059			2287

A. The Nominal Traffic Load (NTL) is defined as the ratio of the number of messages transmitted per minute over the total number of slots per superframe (=4500). NTL does not take into account slot re-use.

B. Two-slot messages transmitted by A2/A3 systems (TCP info), will be treated in the simulation as two separate single slot messages.

The SPS cannot handle the rate of 7 slots per minute. In the simulations some A2/A3 systems will be set to the rate of 10 slots per minute and the rest to 6 per minute, so the the total number of slots per minute is maintained.

This will be done as follows:

There are 39+7 = 46 stations that need to transmit 7 msg/min, using a total of 7x46=322 slots. Instead, 12 of these stations will transmit 10 msg/min, and the other 34 will transmit 6 msg, using 120+6x34=324 slots.

C. **Second Scenario**

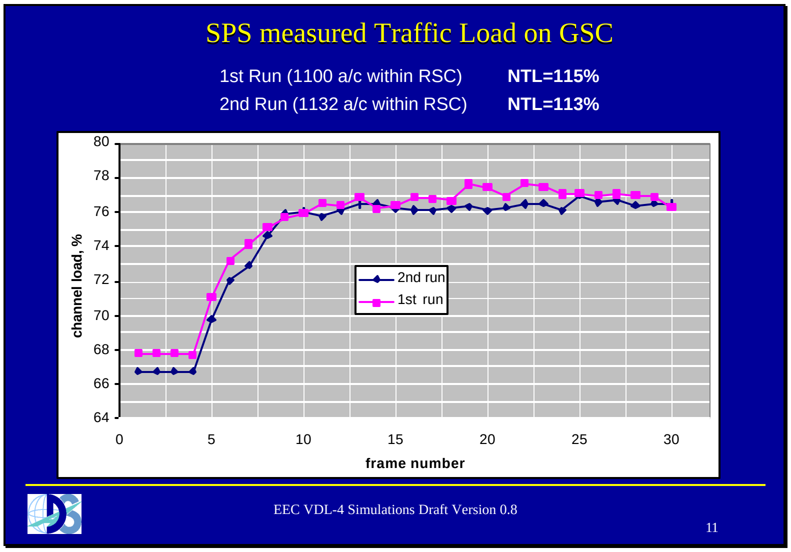
Within RSC coverage there are

	Ground			TMA			En-Route		
Class	Aircraft	Slots /min	Load /min	Aircraft	Slots /min	Load /min	Aircraft	Slots /min	Load /min
GA	24	1	24	119	1	119	99	1	99
0/A1 non GA	30	1	30	123	1	123	103	1	103
A2/A3	79	1	79	183	1	183	161	1	161
				183	2	366	161	2	322
al Aircraft	**133**			**608**			**524**		
al Load ts/min			**133**			**791**			**685**

and outside RSC coverage there are 2091 - 1265 = 826 airborne and 150-133 = 17 ground moving aircraft

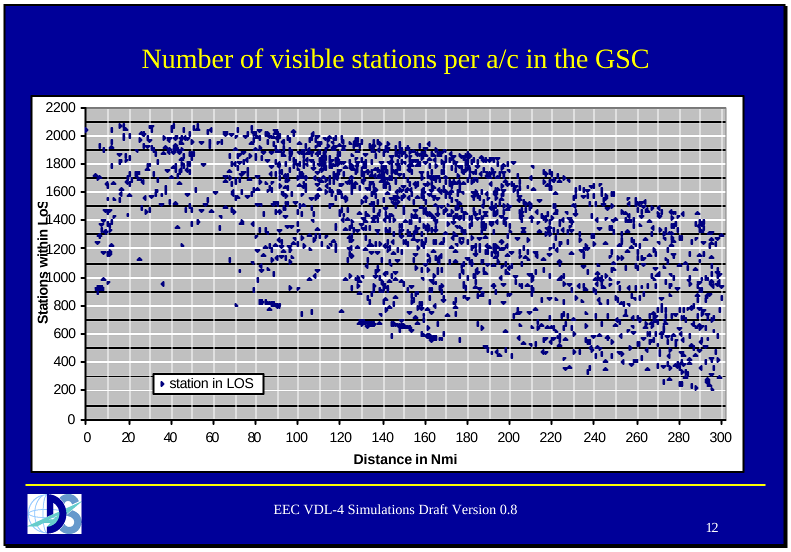
	Ground			TMA			En-Route		
Class	Aircraft	Slots /min	Load /min	Aircraft	Slots /min	Load /min	Aircraft	Slots /min	Load /min
GA	6	3	18	41	3	123	129	3	387
A1 non GA ve FL 100				10	3	30	59	3	177
A1 non GA ow 100 FL	0	1	0	32	6	192	61	6	366
A2/A3 ve FL100				21 21	3 4	63 84	170 169	3 4	510 676
A2/A3 ow FL100	11	1	11	39 38 28/10	6 7 6/10	234 268	10 9 7/2	6 7 6/10	60 62
Aircraft	**17**			**202**			**607**		
Load min			**29**			**994**			**2238**

Slide 11



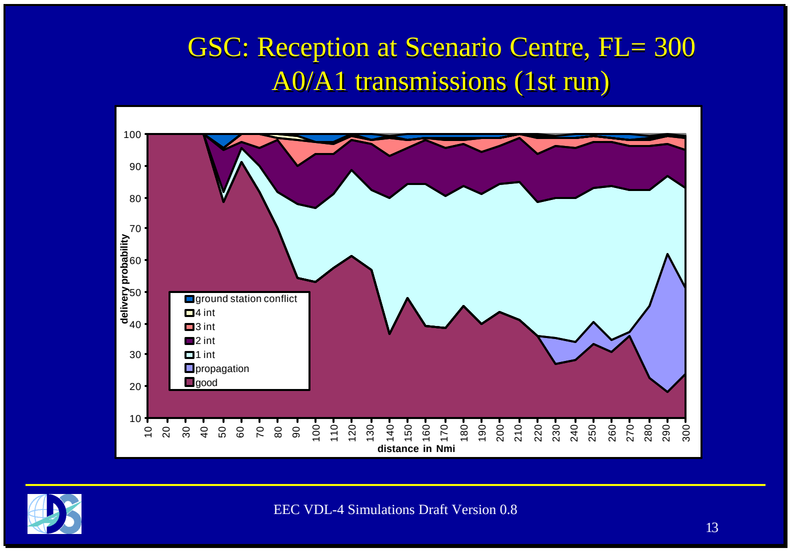
Traffic load is plotted at the end of each superframe as measured by the SPS on GSC1.
SPS measures traffic load as the percentage of active slots over a superframe (4500 slots).
A slot is active if there is at least one transmission taking place in that slot.
A slot that has been reserved but no transmissions take place in it, is not considered as active.
The above slide shows that steady state was reached from the 12th frame onwards.
In both runs the traffic load stabilized at 76-77%, hence 23% of the slots per superframe were free.
Simulation of GSC2 produced practically identical results (as expected).

Slide 12



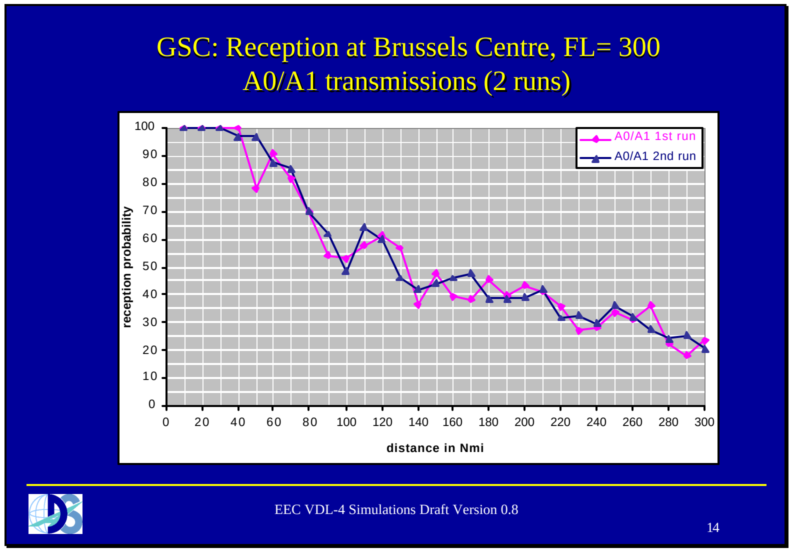
This figure shows for each station in CE2015 (hence in the GSC context - 1st Scenario) the number of other VDL-4 stations that lie within its line of sight (round earth x4/3).
A dot is plotted for each station with x-value = its distance from the scenario center (Brussels) and y-value = the number of stations it sees.
The observation point at Brussels center (FL 300) sees practically all the aircraft in CE2015.
A ground moving aircraft at Brussels center would have only 900 aircraft within LoS
Note that
a. There is little change in LoS numbers up to about 60 nmi from Brussels center;
b. Low flying aircraft see fewer stations hence have to compete with more hidden terminals as transmitters;
c. Worst case reception performance is at the highest altitude because the receiver sees the most stations and hence has to deal with conflicting transmissions from the maximum number of hidden terminals.

Slide 13



This figure plots the reception probability for A1/A0 transmissions at Brussels Centre (FL 300) from the log of the GSC simulation run. The probabilities values have been calculated over the last 10 superframes of a single 30-superframe run. Distance is measured horizontally with no slant correction.
This figure also shows the contributions in lost messages from 1,2,3, .. Interferers as well as signal attenuation.
It is clear that the main reason for loosing messages is garbling due to hidden terminals. Note also that there were message conflicts on ground slots, which mean that some aircraft used the slots reserved for ground station uplinks although they were within coverage of the ground stations concerned.

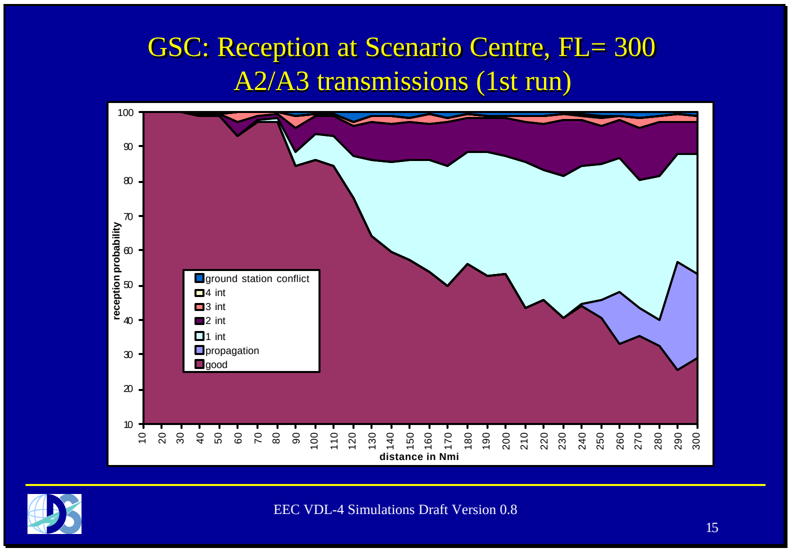
Slide 14



This figure compares the reception probabilities at Brussels center, FL300, from A0/A1 transmitters calculated in the two simulation runs.

In both cases performance starts declining at 40 nmi and at 90 nmi it has fallen below 65%.

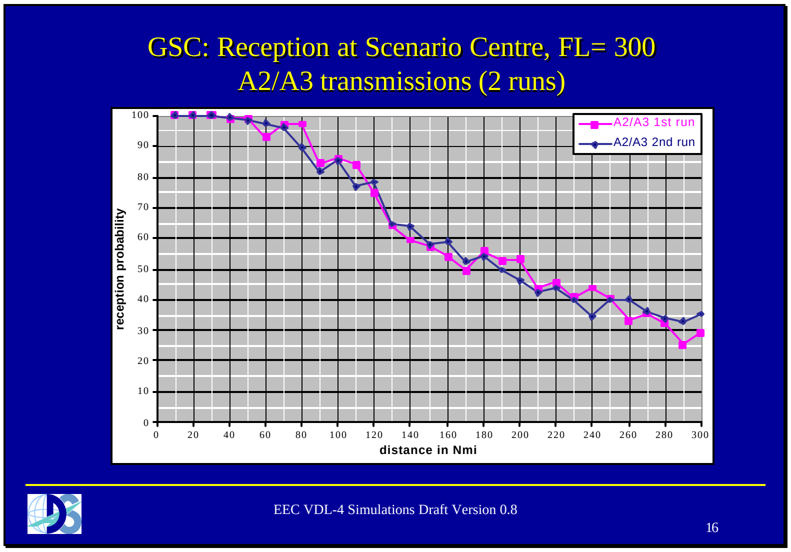
Slide 15



This figure plots the reception probability chart for A3/A2 transmissions at Brussels Centre (FL 300) from the log of the GSC simulation run. A3/A2 transmissions use higher transmission power (~3 dB) but have the same sensitivity as A1/A0. The probabilities values have been calculated over the last 10 superframes of a single 30-superframe run. Distance is measured horizontally with no slant correction.

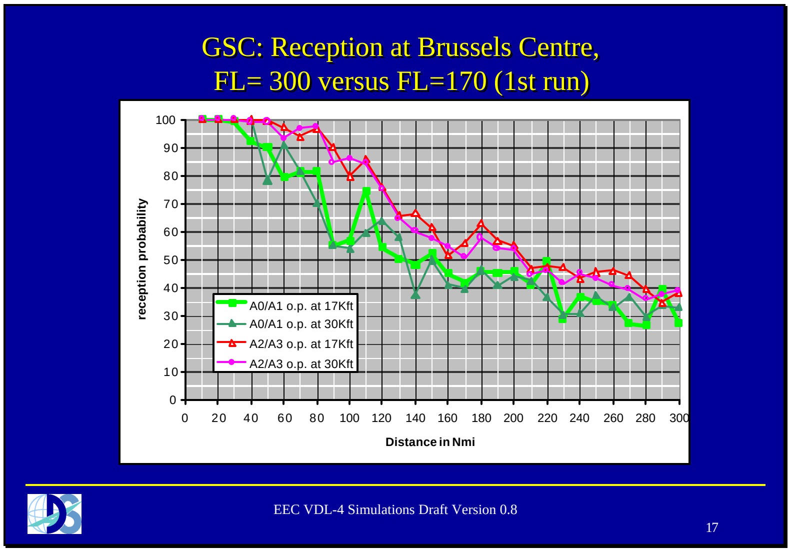
Clearly, message loss is primarily due to collisions (e.g. hidden terminals). Ground reserved slots are not respected due to SPS limitations.

Slide 16



This figure compares the reception probabilities for A2/A3 transmitters at Brussels center (FL300) from the two simulation runs.
Performance starts to drop at 60 nmi, at 90 nmi it has fallen below 85%, at 120 nmi below 80%, and at 150 nmi below 60%.

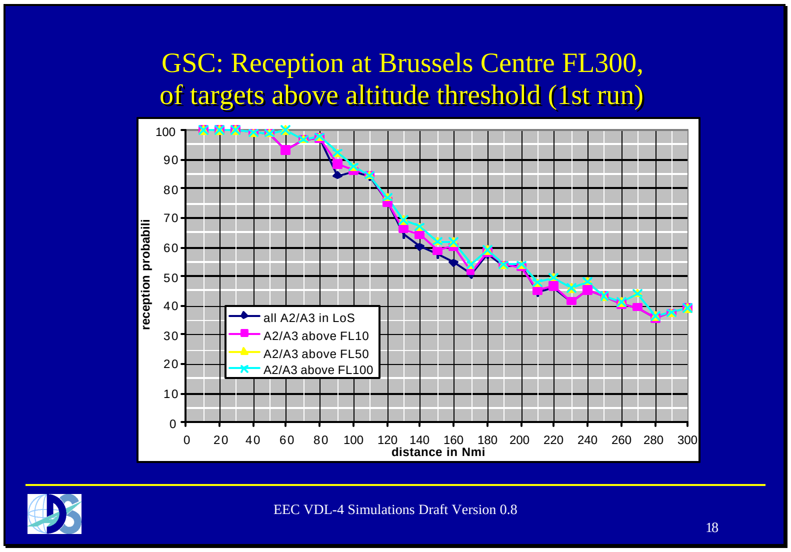
Slide 17



Performance is compared for reception at FL=300 and FL=170 (Brussels center), separately for A0/A1 and A2/A3 transmitters. The FL170 target receiver was a scenario aircraft located 9 nmi from Brussels centre.

Note that the radio horizon of FL150 is around 150 nmi. Nevertheless there is hardly any difference between the performances of the two target receivers. This seems counter-intuitive because at FL150 one would expect to see fewer low lying aircraft whose transmissions would be more likely to be interfered with. It would appear that the chance of receiving these aircraft is in any case too low to make a difference in the results.

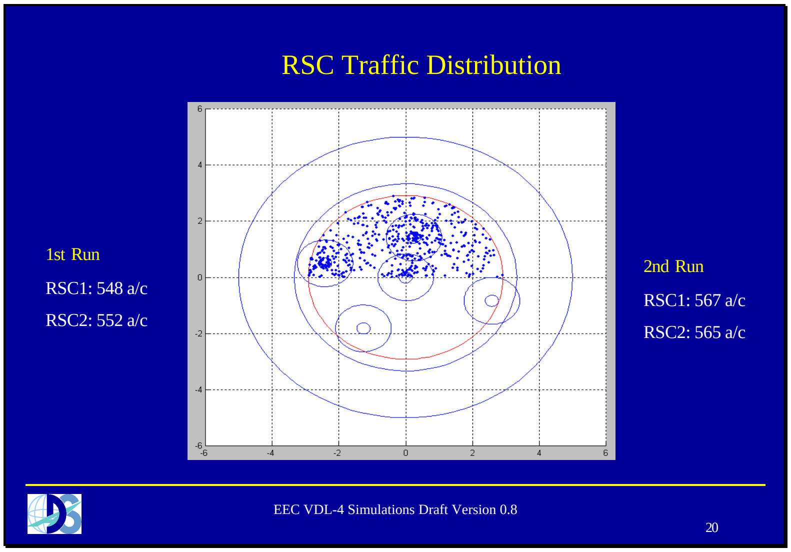
Slide 18



Reception probability calculations included only those targets that were above the indicated altitude threshold. It was expected that performance would improve if low lying targets are excluded. However the results show no performance impact.

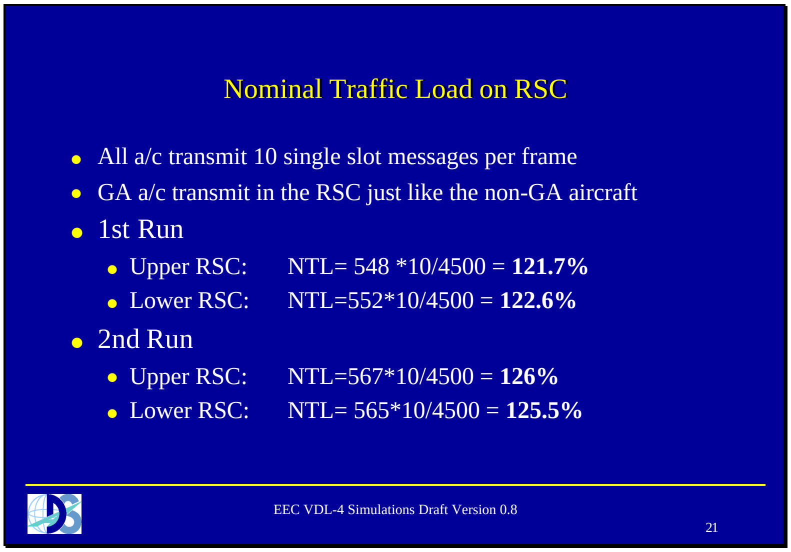
Slide 19

Slide 20



This figure refers to the first run and shows only the positions of the aircraft within the upper RSC extracted form the distribution shown in the previous slide.

Slide 21



The attached tables show the distribution of equipment classes in the upper RSC region.

1st Run

Aircraft Class	Ground Aircraft	Airborne Aircraft	% of total
A0	0	47	8.5
A1	0	165	30.1
A2	0	172	31.5
A3	0	164	29.9
Total	0	548	100

Region	Alt Band	Total	A0	A1	A2	A3	GA
Core En-Route	L	18	7	10	1	0	9
	M	38	16	19	2	1	18
	H	105	0	45	31	29	22
	U	97	0	0	46	51	0
Total		*258*	*23*	*74*	*80*	*81*	*49*
Core TMA Inner	L	43	4	12	13	14	9
(Bruss., Paris, Amst.)	M	25	2	9	6	8	5
Total		*68*	*6*	*21*	*19*	*22*	*14*
Core TMA Outer	M	71	18	16	21	16	19
(Bruss., Paris, Amst.)	H	151	0	54	52	45	28
Total		*222*	*18*	*70*	*73*	*61*	*47*
TOTAL		548	47	165	172	164	110

2nd Run

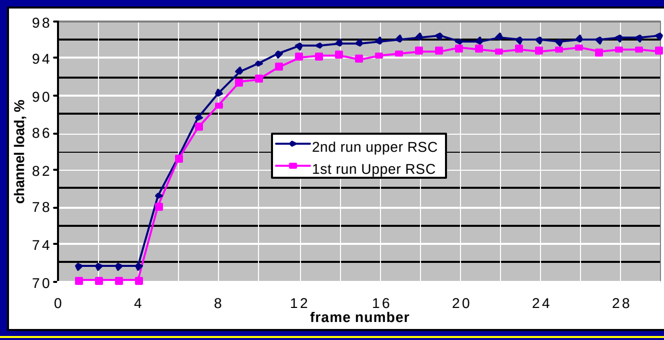
Aircraft Class	Ground Aircraft	Airborne Aircraft	% of total
A0	0	58	10.22
A1	0	174	30.68
A2	0	160	28.21
A3	0	175	30.86
Total	0	567	100

Region	Alt Band	Total	A0	A1	A2	A3	GA
Core En-Route	L	17	11	6	0	0	8
	M	33	18	15	0	0	17
	H	108	0	62	18	28	30
	U	105	0	0	56	49	0
Total		*263*	*29*	*83*	*74*	*77*	*55*
Core TMA Inner	L	47	5	11	15	16	9
(Bruss., London, Amst.)	M	24	3	10	4	7	5
Total		*71*	*8*	*21*	*19*	*23*	*14*
Core TMA Outer	M	80	21	17	19	23	19
(Bruss., London, Amst.)	H	153	0	53	48	52	27
Total		*233*	*21*	*70*	*67*	*75*	*46*
TOTAL		567	58	174	160	175	115

Slide 22

SPS measured Traffic Load on RSC

	Upper RSC			Lower RSC		
Run	a/c	NTL, %	**TL, %**	a/c	NTL, %	**TL, %**
1	548	121.7	**94.8**	552	122.7	**94.1**
2	567	126	**96.4**	565	125.6	**94.3**



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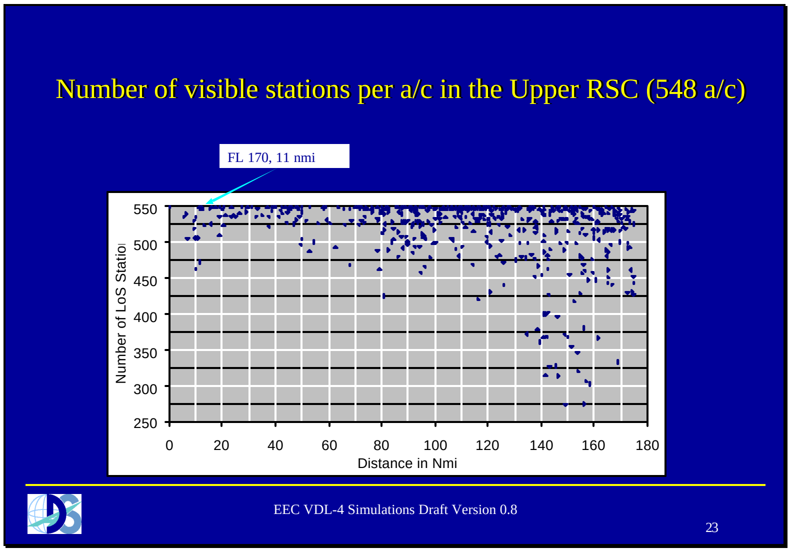
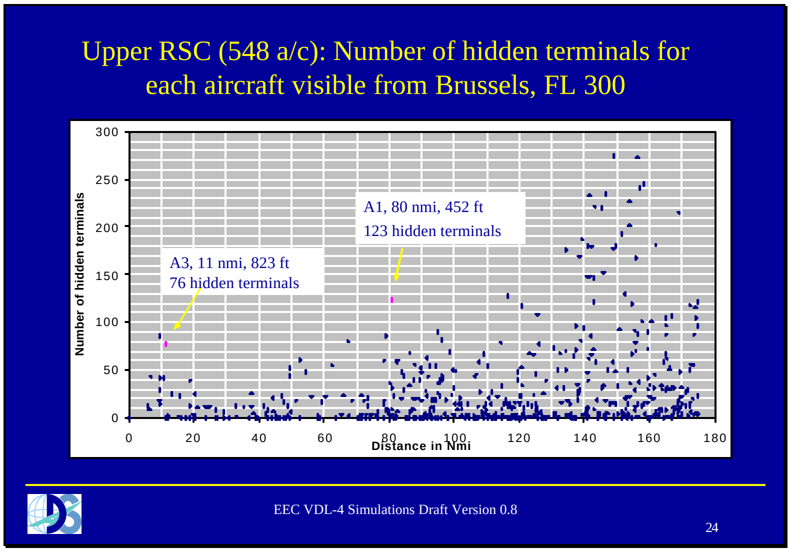
The value of the upper RSC traffic load is plotted at the end of each superframe during the two simulation runs.
Steady state was reached after the 12th superframe.
At the end of superframe 30 the number of active slots was found to be 4266 (1st run) and 4338 (2nd run).
The simulations of the lower RSC produced similar results). At the end of superframe 30 the number of active slots was found to be 4235 (1st run) and 4245 (2nd run) .

Slide 23



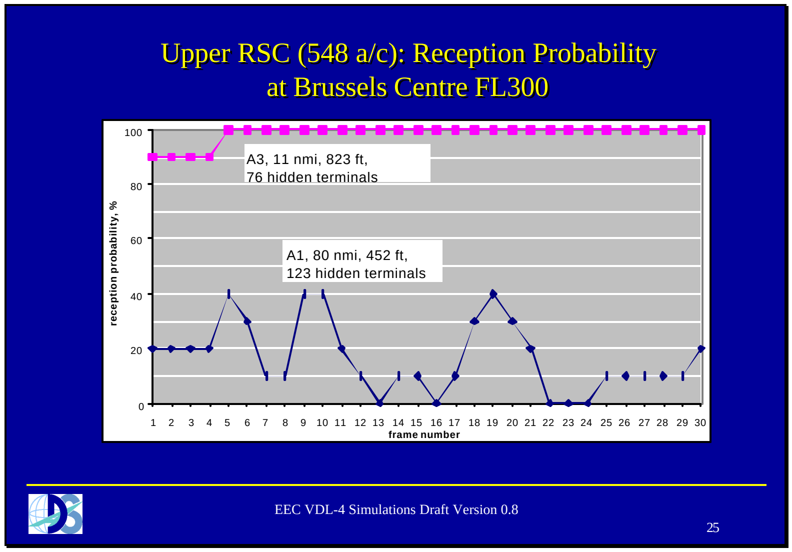
A dot is plotted for each a/c in the upper RSC (1st run) with x-value=distance from Brussels center and y-value=number stations in sees (round earth x4/3)
High altitude aircraft (FL>150) see practically all the stations in the scenario.
Worst case performance should be at FL300 as in the GSC case.
The reception performance of the aircraft identified in the figure was analysed in parallel with that of the observation point in Brussels (FL300). Reception probability was found to be practically identical.

Slide 24



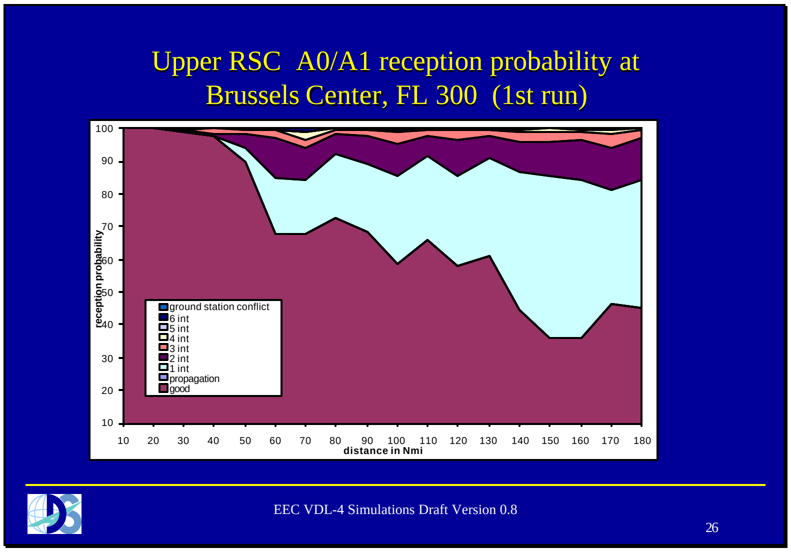
A dot is plotted for each aircraft visible from Brussels center at FL300, with x-value=distance from Brussels center, and y-value=number of hidden terminals in the upper RSC (1st run).
The performance of the two aircraft identified in the plot was calculated in parallel with the average performance, for comparison purposes.

Slide 25



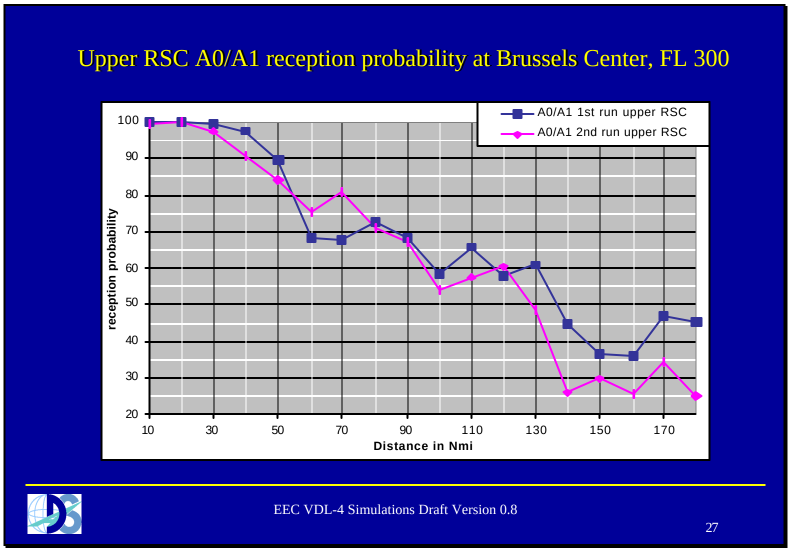
This chart plots the reception probabilities of two specific targets for the victim receiver at FL 300, Brussels Center. Both are at low altitudes but not on the ground. The big difference in performance is due to the 3-dB difference in TX power and the distance from the victim receiver. This makes the A1 station much more vulnerable to interference from hidden terminals, and it has many.

Slide 26



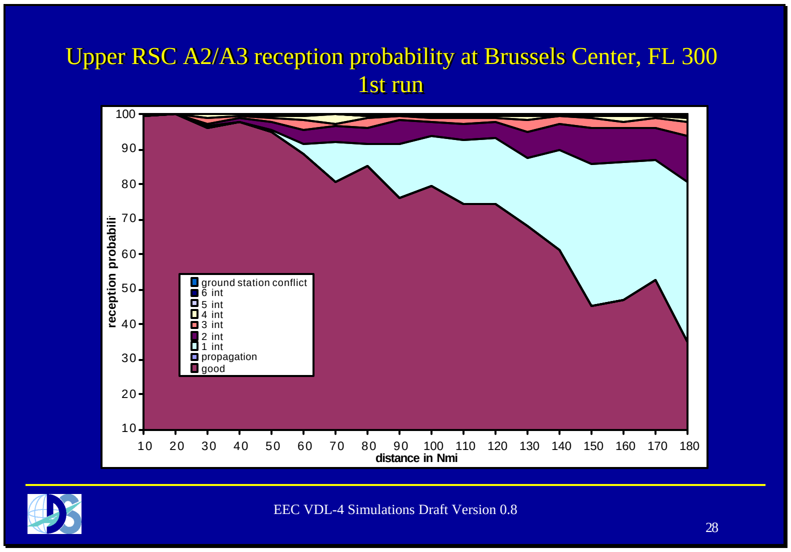
This figure plots the reception probability chart for A1/A0 transmissions at Brussels Centre (FL 300) from the log of the RSC simulation run. The probabilities values have been calculated over the last 10 superframes of one 30-superframe run. Distance is measured horizontally with no slant correction.
It can be seen that A0/A1 performance on the RSC starts to drop at around 30 nmi from Brussels Centre.
Unlike the GSC there are no losses due to signal propagation because of the limited radius of the scenario

Slide 27



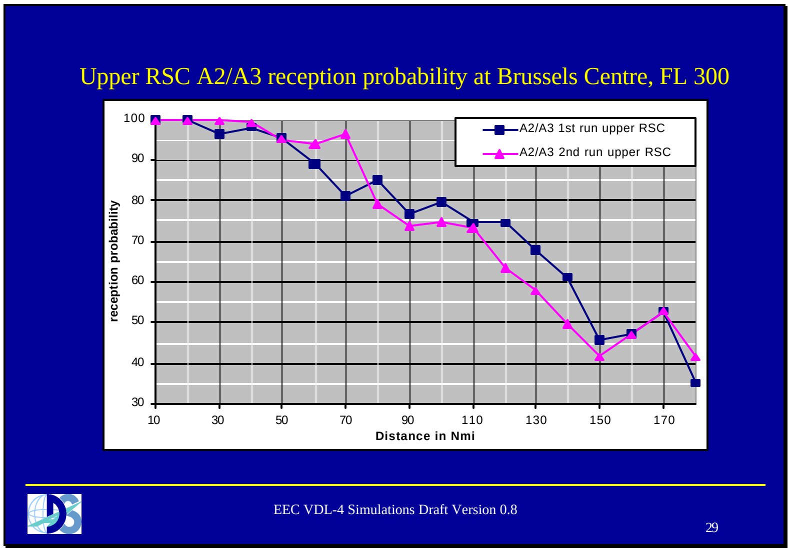
This figure compares the reception probabilities of A0/A1 transmissions at Brussels Center o the three channels (GSC, Upper RSC, and Lower RSC).
RSC reception performance starts to drop from 20 nmi and falls to 95% at 30 nmi, 90% at 40 nmi, <85% at 60 nmi and 65% at 90 nmi.
GSC performance tends to be somewhat better than the two RSC at least up to 60 nmi.

Slide 28



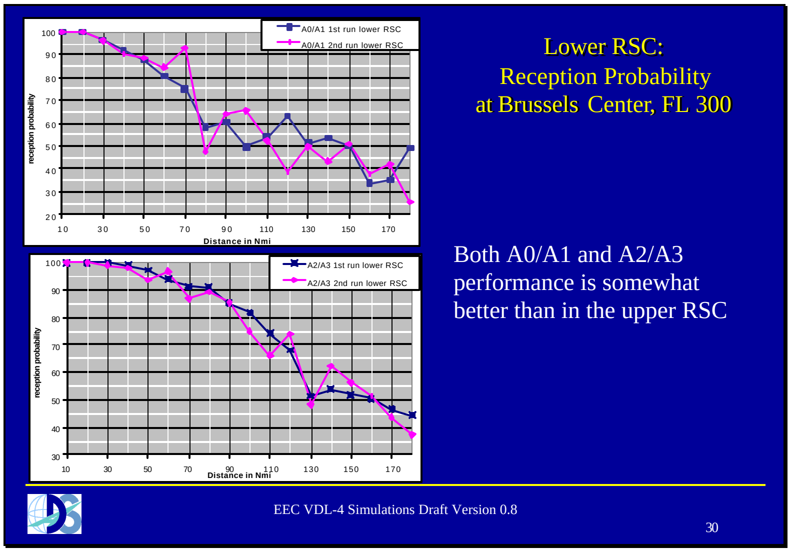
This figure plots the reception probability chart for A3/A2 transmissions at Brussels Centre (FL 300) from the log of the RSC simulation run. The probabilities values have been calculated over the last 10 superframes of a single 30-superframe run. Distance is measured horizontally with no slant correction.
It can be seen that A3/A2 performance on the RSC starts to drop at around 30 nmi from Brussels Centre.

Slide 29



This figure compares the reception probabilities of A2/A3 transmissions at Brussels Centre that were shown in the previous RSC and GSC simulation result slides.

Slide 30

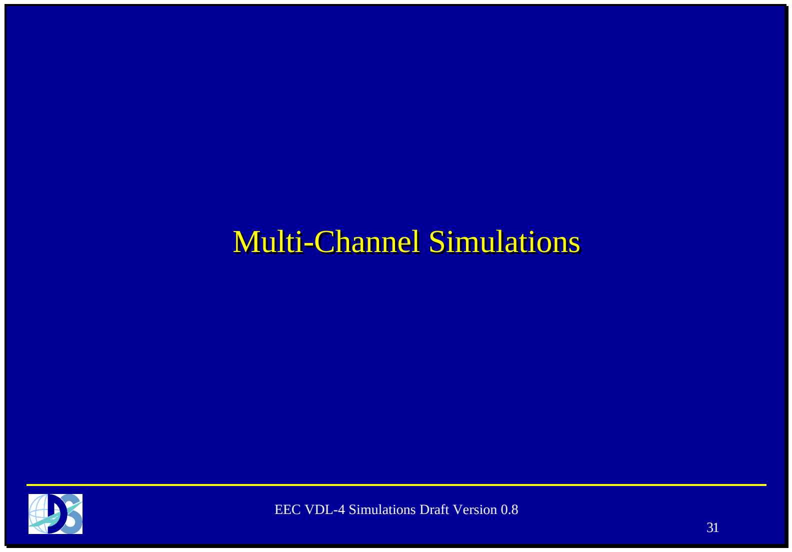


This chart shows the message reception probabilities for a victim receiver placed at the scenario centre (Brussels) and altitude FL300 from all targets within the lower RSC. Distance is measured from the victim receiver (horizontal).

The observed differences with the upper RSC are :

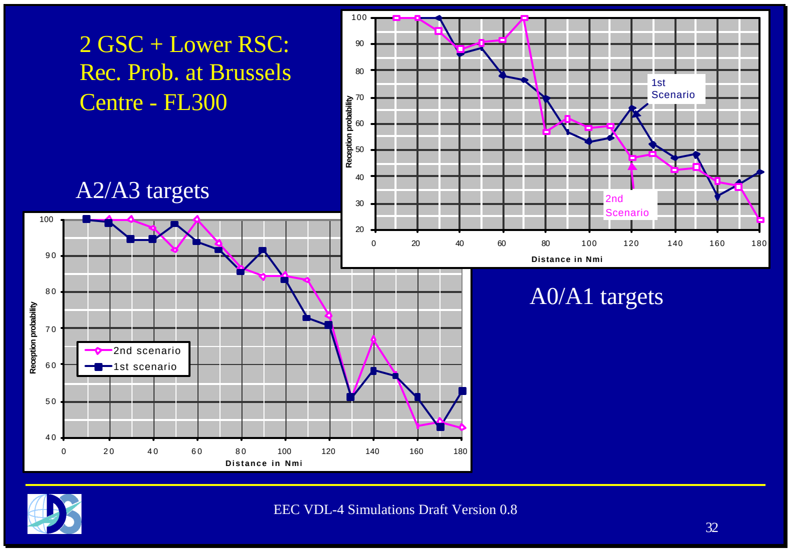
- A2/A3 reception probability is maintained above 80% up to 95-105nmi in the Lower RSC and 80-85 nmi in the Upper RSC
- A0/A1 reception probability is maintained above 80% up to 60-75 nmi in the Lower RSC and 55 nmi in the Upper RSC

Slide 31



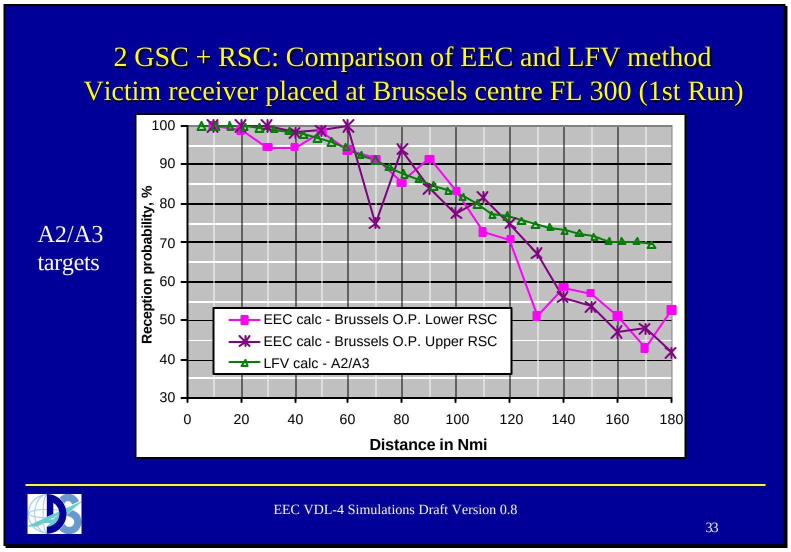
Two multichannel simulations were run using the two traffic scenario instantiations. The logs from each run were analyzed for two cases 2 GSC + Upper RSC and 2 GSC plus Lower RSC, thus providing four analysis cases in total.
In draft version 0.8, multi-channel simulations do not include the TLAT antenna gain model.

Slide 32



Reception Probability has been calculated from the logs produced by the multi-channel simulation for a victim receiver located at Brussels centre and altitude 30000ft. The targets are grouped according to 10 nmi wide distance bins from the victim receiver and the number of messages received from them is divided by the number of transmitted messages to obtain an estimate of reception probability. The latter is calculated separately for A2/A3 and A0/A1 transmitters, since they differ in transmission power. Furthermore the reception probability is calculated separately for the logs 2 GSC plus Upper RSC and 2 GSC plus Lower RSC.
The multi-channel simulation was run separately for each of the two CE215 traffic scenario instantiations that have been used all along.
In the above shown graphs, only those targets that are within the Lower RSC have been included in the reception probability calculation. The A2/A3 performance calculations have excluded targets transmitting intent.
The observed reception probability values are dominated by the reception probabilities of the RSC channel, since targets within the latter transmit 10 messages per minute in it and only one per message in each GSC.
Note that in both runs A2/A3 reception probability stays above 80% all the way to 100 nmi.
For A0/A1 targets the reception probability stays above 80% only up to 60-70 nmi.

Slide 33

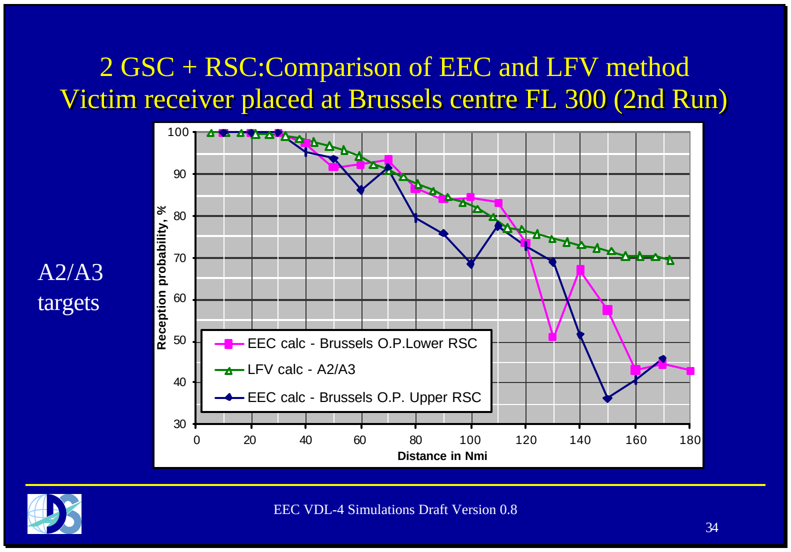


For comparison purposes, the reception performance of the Brussels FL 300 observation point calculated according to the EEC method from the 2 GSC plus Lower RSC logs is compared with the results produced by the multi-channel performance analysis tool developed by LFV. The latter tool does not calculate the reception probabilities at a specific victim receiver but rather an average of the performance of all transmitters and receivers within the scenario.

The LFV method appears to produce more optimistic results for the longer ranges.

Note also the significant difference between Upper and Lower RSC results. In the case 2 GSC+Upper RSC, the victim receiver at 30Kft achieves >80% reception probability for A2/A3 targets only for up to 65 nmi. In the case of 2GSC+Lower RSC the equivalent range is 105 nmi.

Slide 34

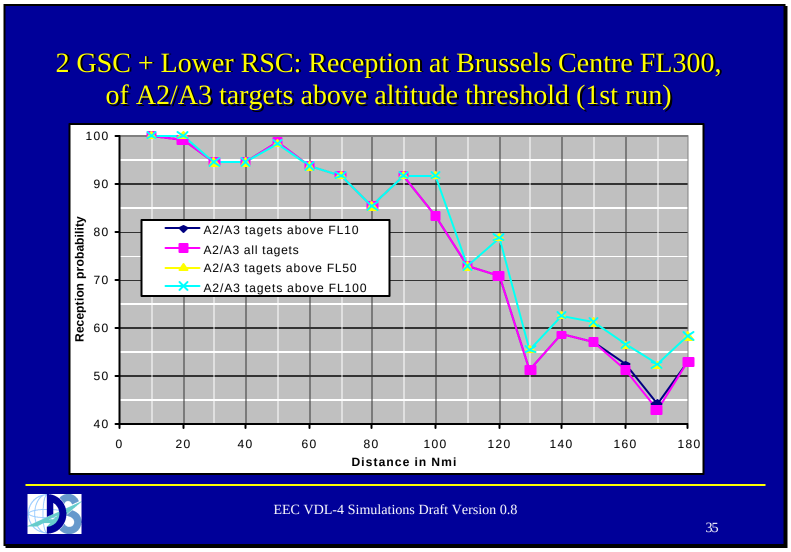


This is the same chart as in the previous slide calculated for the second CE2015 traffic scenario instantiation. The same observations apply.

As noticed in the previous slide, there are significant differences in the observed performance between 2 GSC+ Lower RSC and 2 GSC plus Upper RSC. In the case 2 GSC+Upper RSC, the victim receiver at 30Kft maintains >80% reception probability for A2/A3 targets only for up to 80 nmi. In the case of 2 GSC+Lower RSC the equivalent range is 115 nmi.

The LFV method tends to hide such differences. Indeed in both runs the 80% range is 110 nmi according to the LFV curves.

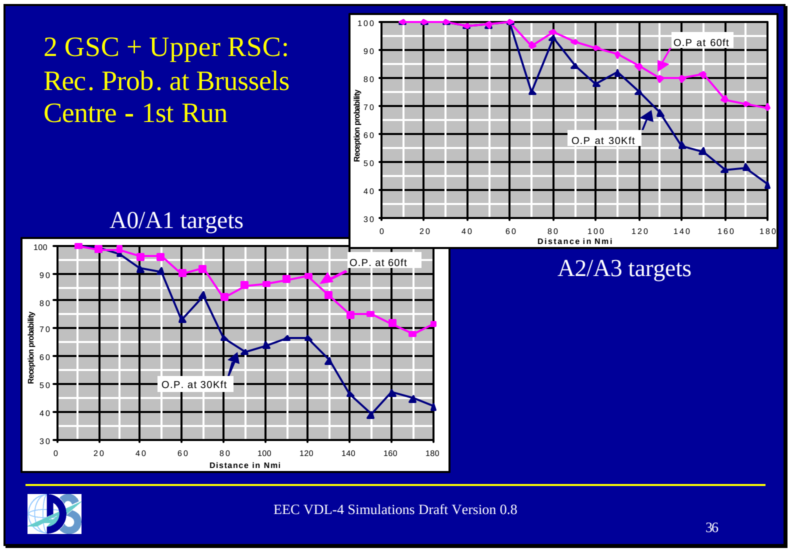
Slide 35



The victim receiver is at the scenario centre, alt 30000ft. Reception probability has been calculated taking into account only targets lying above the specified altitude threshold. It was expected that performance would improve if low lying targets were excluded. The observed improvement seems minor.

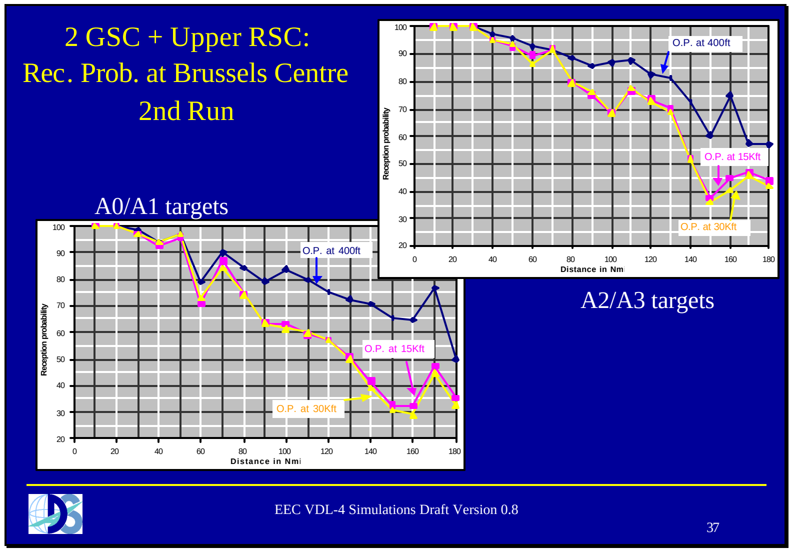
The 2nd run (not shown) produced very similar results.

Slide 36



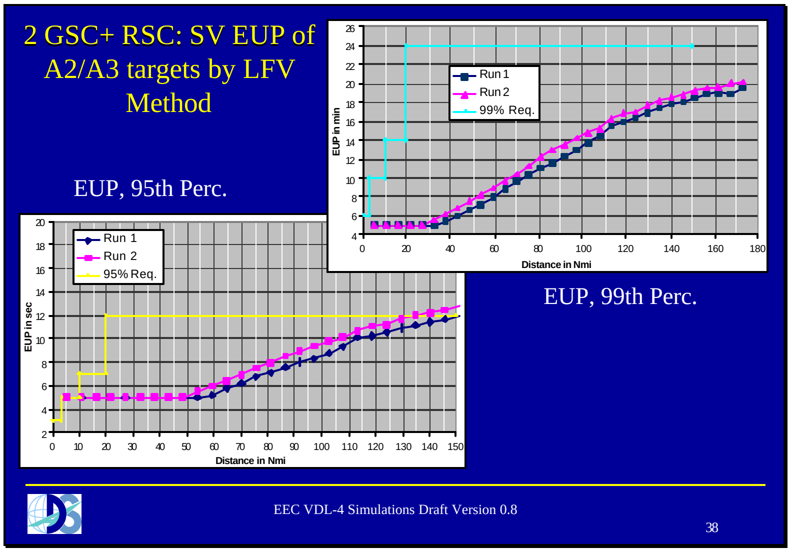
The victim receiver is placed at the scenario center and altitude 60 ft. For comparison the charts also show the case where the victim receiver is at FL300.
Reception probability calculations have taken into account only targets within the upper RSC (not transmitting intent in the case of A2/A3).
The received probability was calculated at the 30th superframe.
There is noticeable difference between the reception probabilities at the two victim receivers.
Unlike the case of A2/A3 targets, there is no noticeable performance difference in the case of A0/A1 targets between 2GSC+Upper RSC and 2 GSC plus Lower RSC. The victim receiver at 30 Kft maintains >80% reception probability up to 55 nmi in the 2GSC+Upper RSC case and 60 nmi in the 2GSC+Lower RSC case.

Slide 37



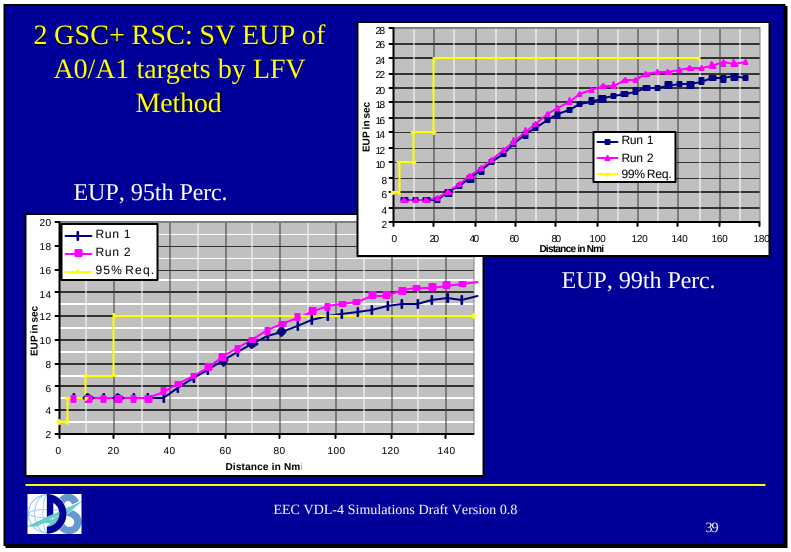
These are the same graphs as in the previous slide, but corresponding to the second instantiation of the CE2015 traffic scenario.
In this case the victim receiver is placed at altitudes 400ft, 15000ft, and 30000ft.
Reception probability calculations have taken into account only targets within the upper RSC (not transmitting intent in the case of A2/A3).
The received probability was calculated at the 30th superframe.
There is little difference between reception performances at FL300 and FL150, while performance improves when the receiver is at 400ft.
There is a difference in the 2GSC+Upper RSC and 2GSC+Lower RSC results for A0/A1 targets. The victim receiver at 30 Kft maintains >80% reception probability up to 55 nmi in the 2GSC+Upper RSC case and 70 nmi in the 2GSC+Lower RSC case.

Slide 38



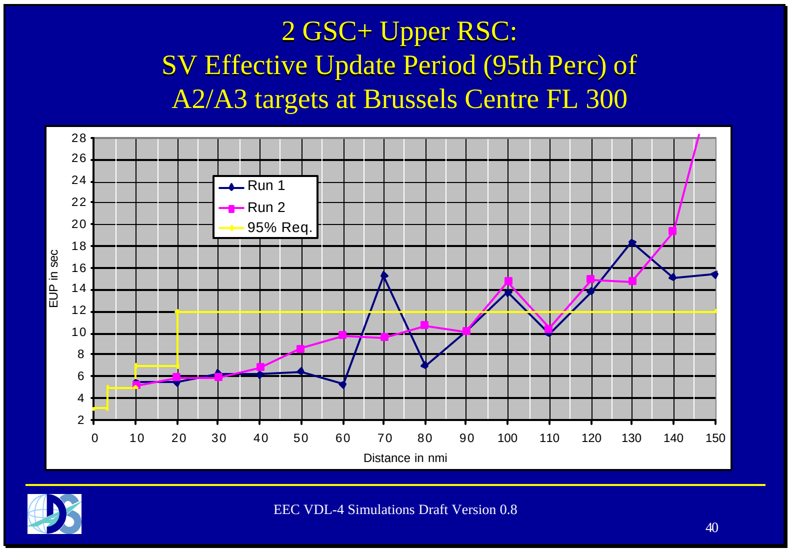
SV EUP = State Vector Effective Update Period.
EUP is the measured time interval between successive report updates.
It is assumed that each VDL-4 message constitutes a state vector update.
The multi-channel simulation logs were analysed using LFV supplied analysis tools.
These tools calculate EUP as a percentile of the observed update interval distribution per distance (from scenario centre) bin (10 km wide) over the whole transmitter and receiver population in the scenario.
The RTCA ADS-B MASPS requirements for state vector updates are also plotted (from Table 3.3 of DO-242). However the LFV method of EUP calculation cannot be considered as producing a reliable measure of EUP as specified in the ADS-B MASPS, because it mixes the performance of low-altitude and high altitude receivers. It has been shown that the latter generally have poorer performance because of their position.

Slide 39



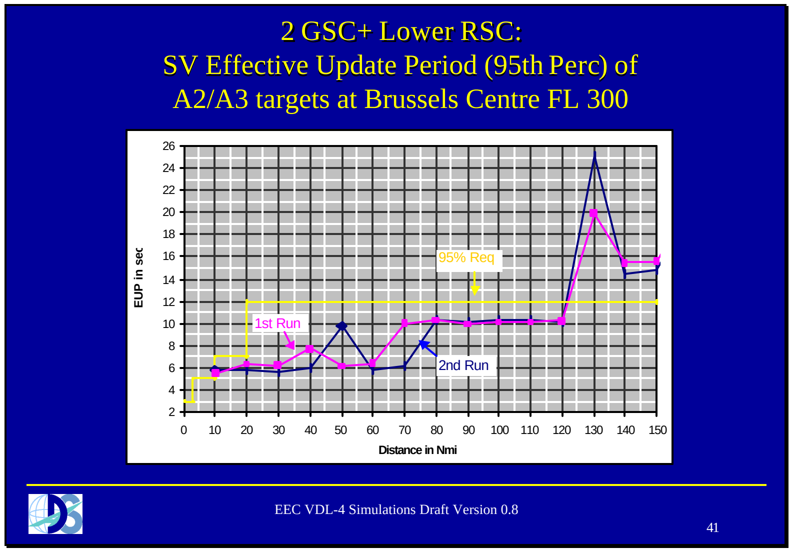
These charts present the EUP for A0/A1 targets calculated according to the LFV method discussed in the previous slide.

Slide 40



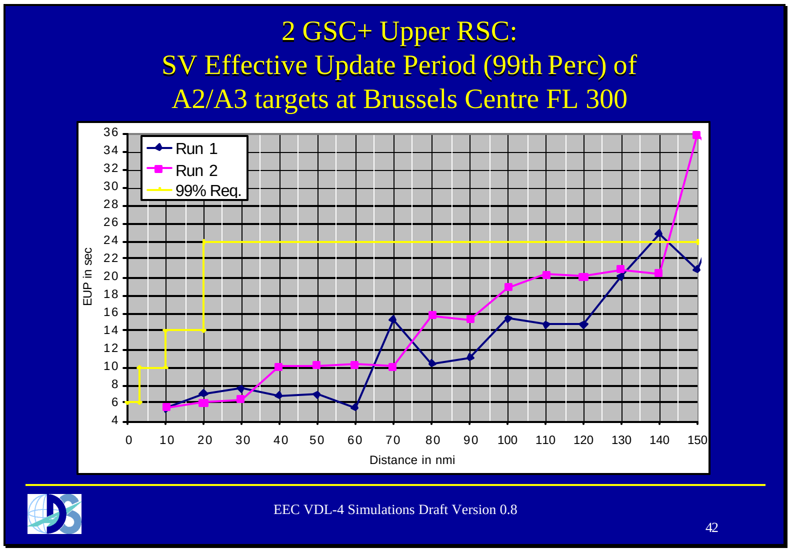
In this case performance has been calculated from the same multi-channel simulation logs as in the previous slides but using EEC developed tools. The latter calculate EUP for a specific receiver, which was positioned at the scenario centre and altitude 30000ft. EUP is calculated as a percentile from the distribution of EUP samples that were measured for all targets lying within a horizontal distance bin (10 nmi wide) and within the 30th simulation superframe. Performance is calculated separately for 2 GSC+ Upper RSC and 2 GSC+ Lower RSC. A2/A3 targets transmitting intent are not included in the calculations because they do not use the same transmission rates as the other stations. The chart shows the calculated EUP 95th percentile values for the two simulation runs and compares with the ADS-B MASPS requirements (table 3.3 of DO-242).
Clearly the EEC method produced less optimistic results than LFV but it is much closer to the ADS-B MASPS definition of EUP requirements.

Slide 41



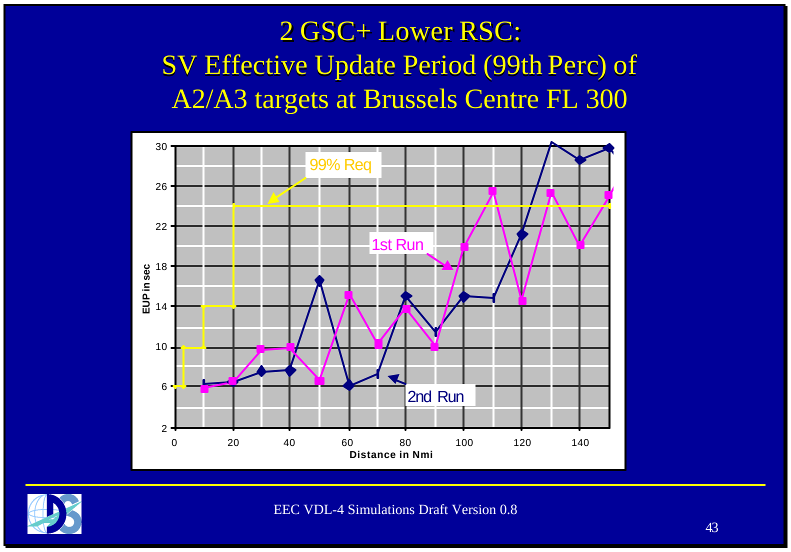
Same chart as in the previous slide but referring to the 2 GSC + Lower RSC logs. Performance is noticeably better. This was expected from the reception probability estimates, shown in previous slides.

Slide 42



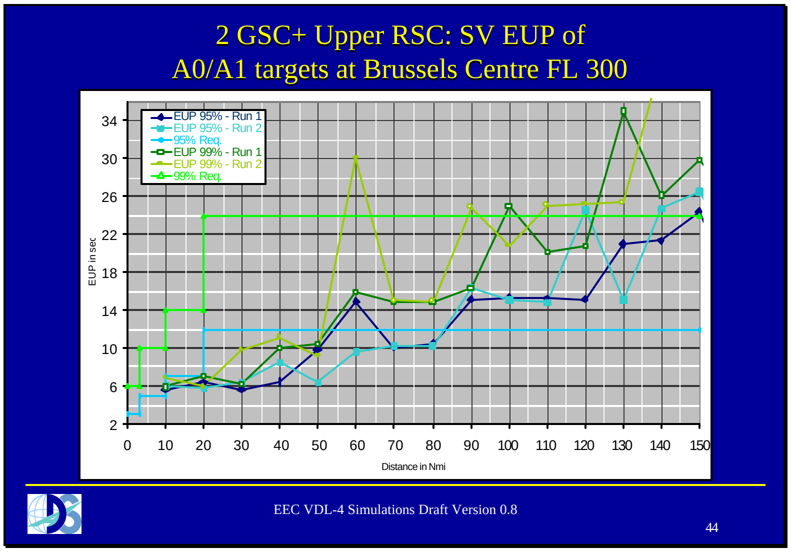
This chart shows the 99th percentile values of the EUP calculated by the EEC method as in the previous slide.

Slide 43



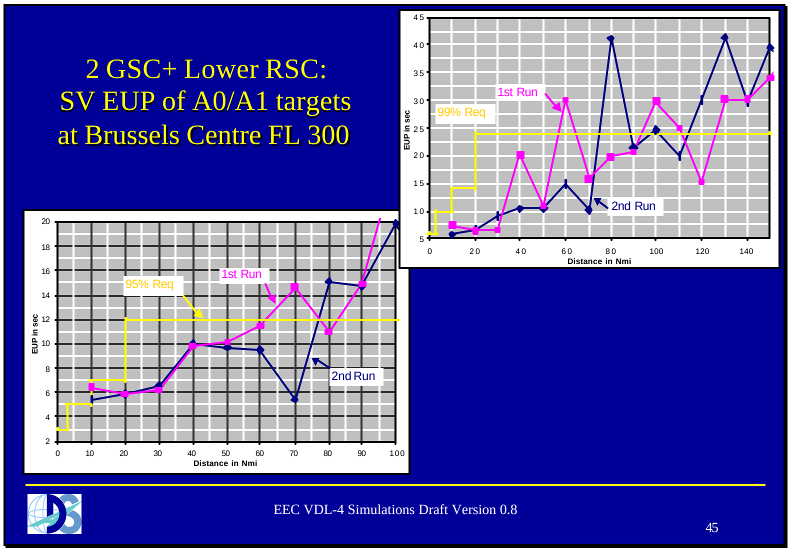
This is the same chart as in the previous slide but presenting the case 2 GSC plus Lower RSC.
The observed 99% EUP values are higher than in the previous slide, and range is here down to 110 to 120 nmi versus 140 in the previous slide.

Slide 44



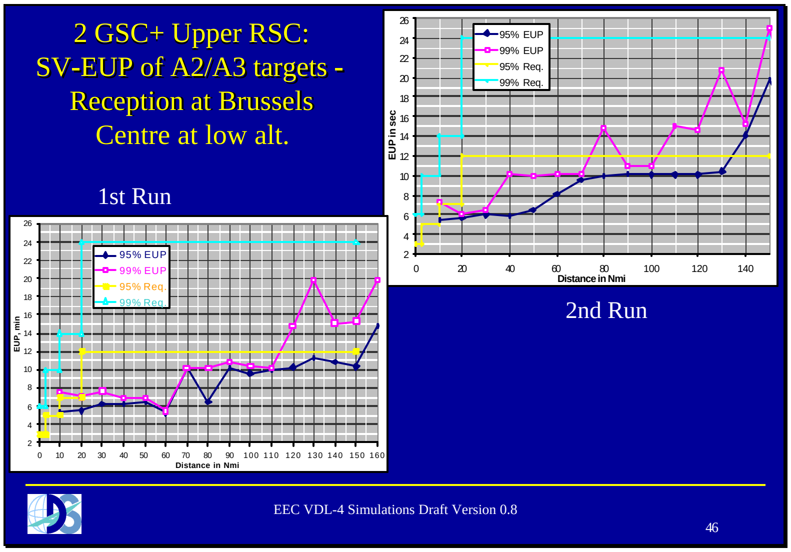
These charts present the EUP measurements for A0/A1 targets, calculated by the EEC method explained in the previous slides.
A0/A1 target performance range is 55-85 nmi for 95% EUP and 55 -100 nmi for 99% EUP.

Slide 45



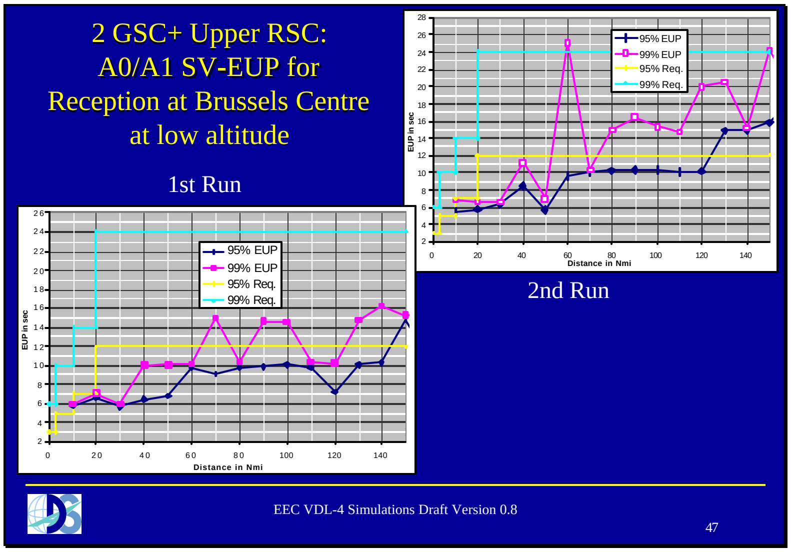
Same chart as in the previous chart, but for the scenario 2 GSC plus Lower RSC.
A0/A1 target performance range is 60-75 nmi for 95% EUP and 55-75 nmi for 99% EUP.

Slide 46



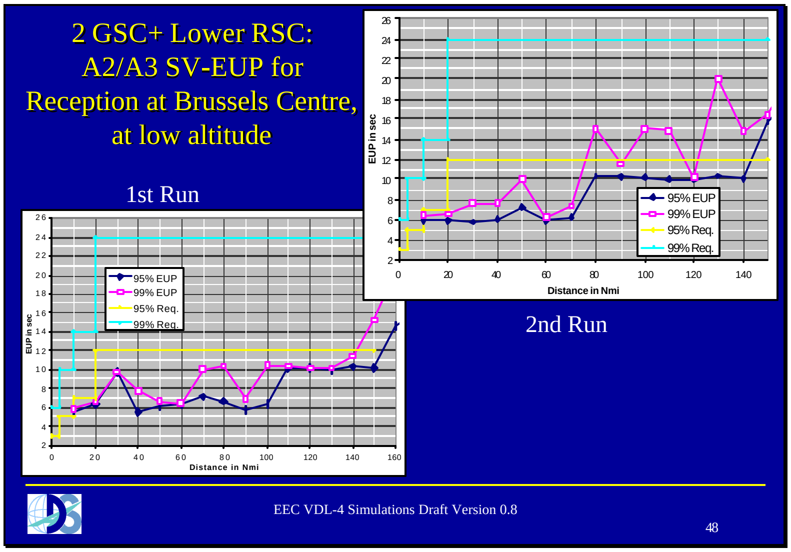
This chart shows the EUP measured by the EEC method in the multi-channel simulation simulation at a victim receiver located at the scenario centre and altitude 60 ft (1st Run) and 400 ft (2nd Run) for the target population 2 GSC + Upper RSC
EUP performance is clearly better than in the case of high altitude victim receiver. This was also observed with the reception probability measurements
The observed a/a range reaches 150 nmi in the first run and 135 nmi in the second run.
If the receiver is assumed to represent a ground station, then the en-route 10sec EUP performance is met up to 70 nmi.
The TMA 5scec performance is not met at all.

Slide 47



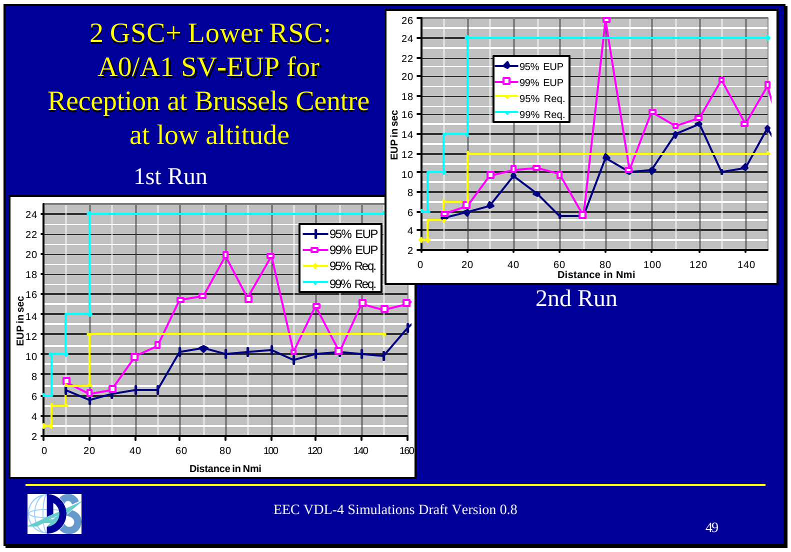
These charts show A0/A1 target performance for the low altitude receiver case described in the previous slide.
The observed performance is again better than what was seen in the high altitude victim receiver case. Indeed 95% EUP range reaches 145 nmi in the 1st run and 125 nmi in the 2nd run. However in the latter case 99% EUP requirement was violated at 60 nmi.
If the receiver is assumed to represent a ground station, then the en-route 10sec EUP performance is met up to 60 nmi (1st run) and 35 nmi (2nd run).
The TMA 5scec performance is not met at all.

Slide 48



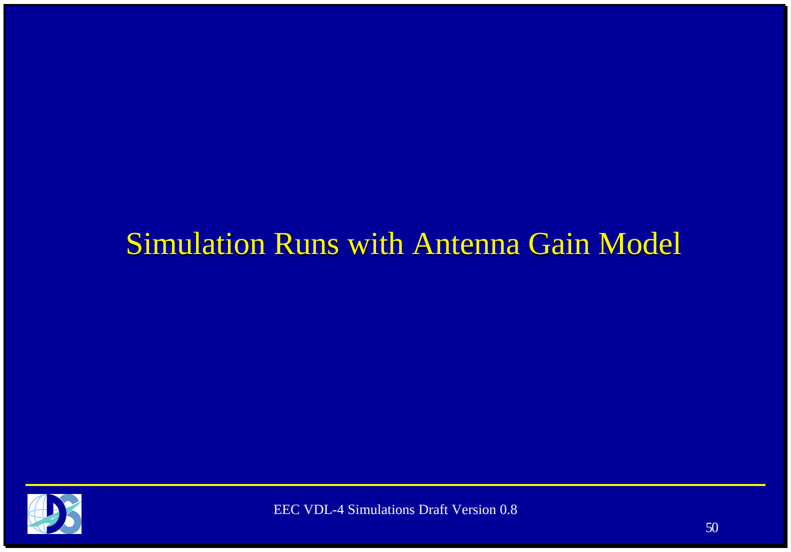
These charts show the low altitude victim receiver case for 2GSC + Lower RSC.
95% EUP range reached 150 nmi in the 1st run and 145 nmi in the 2nd. This is comparable with what was seen in the 2 GSC + Upper RSC case for A2/A3 targets.
If the receiver is assumed to represent a ground station, then the en-route 10sec EUP performance is met up to 70 nmi (1st run) and 50 nmi (2nd run).
The TMA 5scec performance is not met at all.

Slide 49



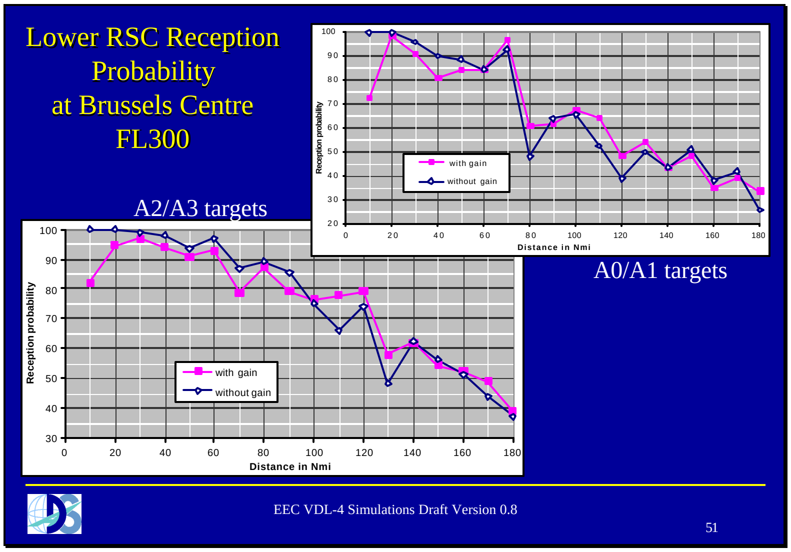
These charts show the low altitude victim receiver case for 2GSC + Lower RSC and A0/A1 targets.
95% EUP range reached 155 nmi in the 1st run but only 105 nmi in the 2nd. In the latter case 99% EUP requirement was violated at 80 nmi. This performance is fairly similar with what was seen in the 2 GSC + Upper RSC case for A0/A1 targets.
If the receiver is assumed to represent a ground station, then the en-route 10sec EUP performance is met up to 40 nmi (1st run) and 70 nmi (2nd run).
The TMA 5scec performance is not met at all.

Slide 50



The simulations presented in the previous slides assumed an omni antenna with zero dB gain and no blocking. The simulations presented in this section assume top and bottom antennas on A2/A3 aircraft and bottom antennas on A0/A1. The antenna gains are determined according to the TLAT model depending on the elevation and azimuth of the target (recalculated every 10 sec assuming rotating aircraft).
Transmissions are assumed to occur alternatively on the top and bottom antenna. Signal strength is calculated separately for top and bottom receiving antennas. The stronger of the two signals is selected.

Slide 51



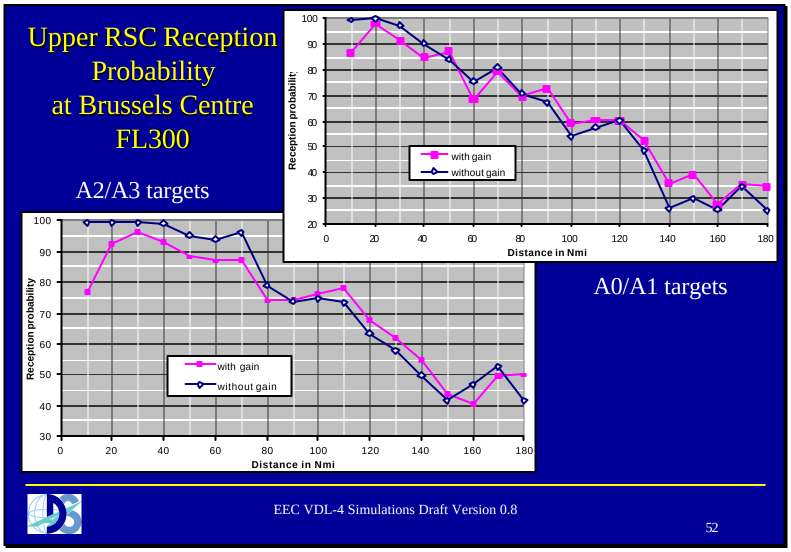
The 2nd instantiation of the traffic scenario has been used. Only the Lower RSC has been simulated.

The victim receiver is at the scenario centre at 30000ft.

Reception probability has been calculated over the last 10 superframes (20 to 30) of the run.

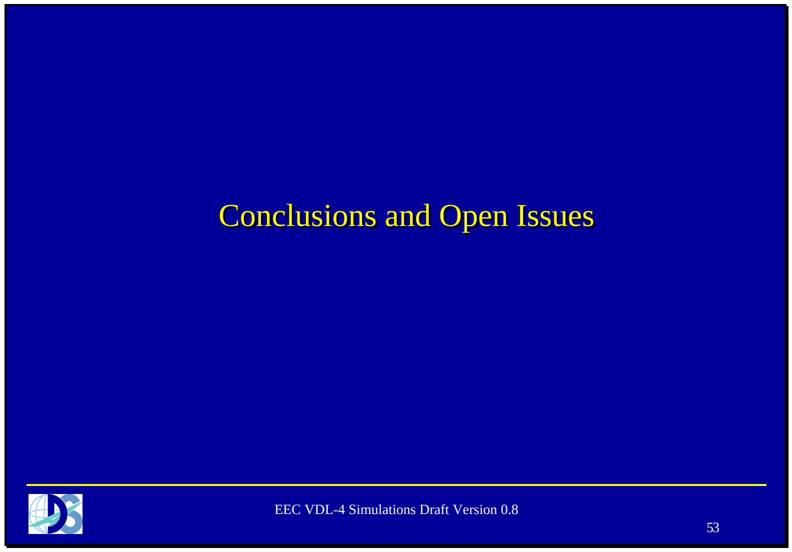
There is a clear cone of silence effect for distances below 20 nmi for A0/A1 targets and 30 nmi for A3/A2 targets. This is because the bottom antenna of targets underneath the victim receiver can be blocked, hence those transmissions are lost. The same applies to the top antenna of targets above the victim receiver.

Slide 52



This chart shows the corresponding results for the Upper RSC.
The same traffic scenario and calculation method was used as in the previous slide.
Again A2/A3 performance drops below 30 nmi, while A0/A1 begins dropping below 20 nmi.

Slide 53


Conclusions and Open Issues
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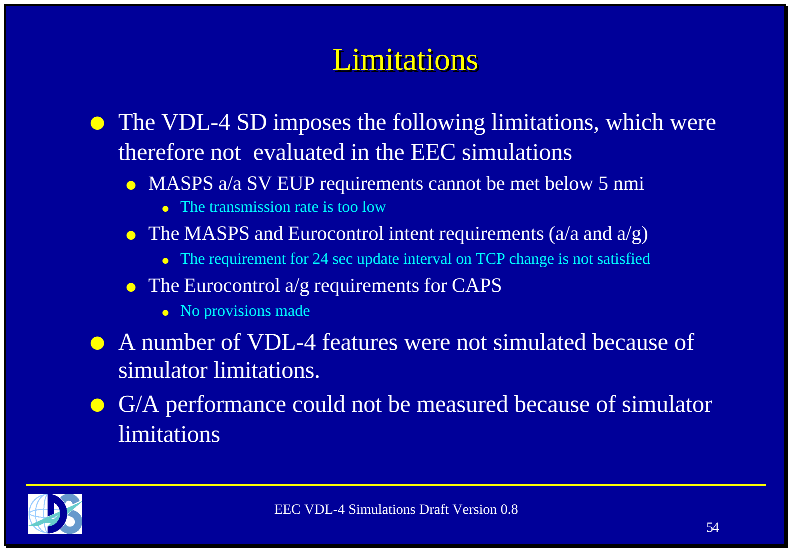
Slide 54


Limitations
The VDL-4 SD imposes the following limitations, which were therefore not evaluated in the EEC simulations
MASPS a/a SV EUP requirements cannot be met below 5 nmi
The transmission rate is too low
The MASPS and Eurocontrol intent requirements (a/a and a/g)
The requirement for 24 sec update interval on TCP change is not satisfied
The Eurocontrol a/g requirements for CAPS
No provisions made
A number of VDL-4 features were not simulated because of simulator limitations.
G/A performance could not be measured because of simulator limitations
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Observations from EEC Simulations

- The EEC results show significant variations between the four scenarios evaluated
  - These variations are hidden by the LFV method
  - There is need for more simulations to evaluate distributions accurately
- It seems that reception probability of 80% or more would be sufficient to keep 95% EUP below the 12sec limit.
  - This is much less than what is indicated by the EUP versus *recprob* formula proposed in the MASPS (which assumes Poisson inter-arrival distribution)
- The impact of the TLAT antenna gain model needs further investigation. Initial comparisons showed that the TLAT antenna gain model
  - caused a 5-8% degradation of reception probability up to 90 to 100 nmi, and an increase beyond 100 nmi.
  - Degradation was stronger at close distances (< 30 nmi), due to antenna blocking
- Measured performance was not sensitive to the altitude of high flying victim receivers, but it improved markedly when the receiver was close to the ground.

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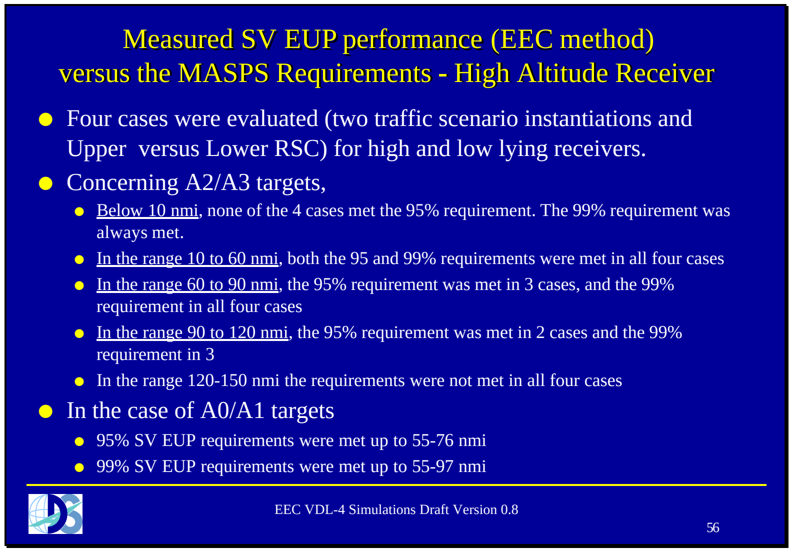
Slide 56



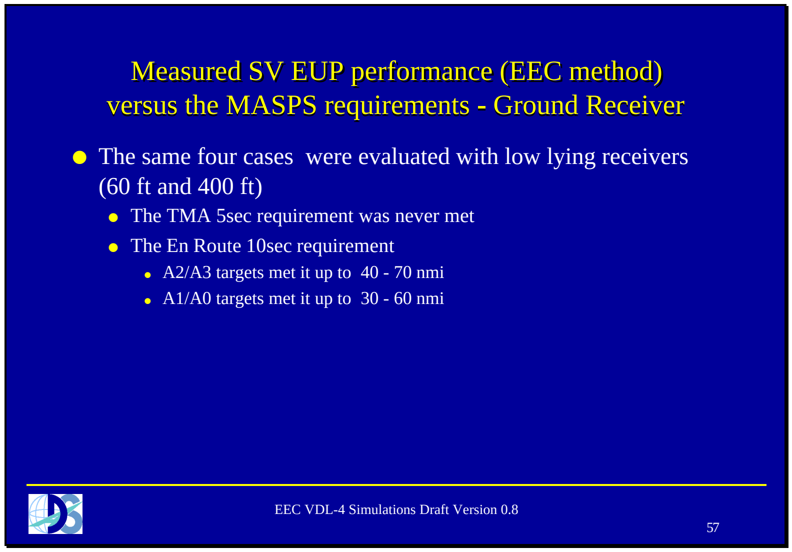
A2/A3 SV EUP range (MASPS table 3.3):

	1st Run	2nd Run	
2GSC + Lower RSC	122	122	95%
	103	122	99%
2GSC + Upper RSC	67	94	95%
	138	142	99%

A1/A0 SV EUP range (MASPS table 3.3):

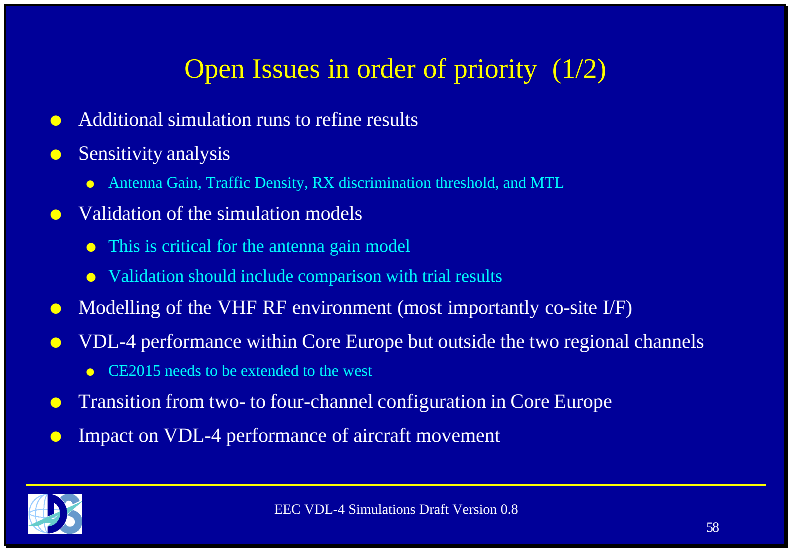
	1st Run	2nd Run	
2GSC + Lower RSC	60	76	95%
	55	72	99%
2GSC + Upper RSC	55	84	95%
	97	56	99%

Slide 57



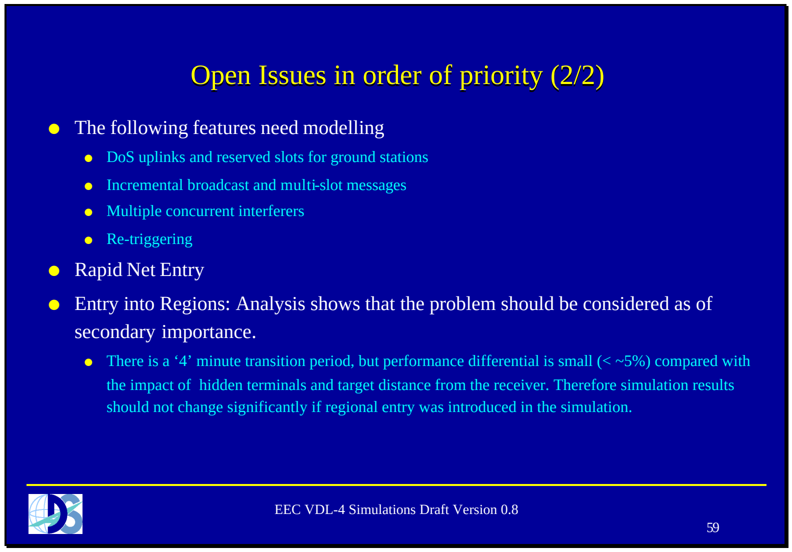
This is the 1st run 2GSC+Upper RSC case where the victim receiver is at 60 ft

Slide 58



The four channel simulation is being done. It will be used to calculate update intervals versus distance

Slide 59


Open Issues in order of priority (2/2)
The following features need modelling
DoS uplinks and reserved slots for ground stations
Incremental broadcast and multi-slot messages
Multiple concurrent interferers
Re-triggering
Rapid Net Entry
Entry into Regions: Analysis shows that the problem should be considered as of secondary importance.
There is a ‘4’ minute transition period, but performance differential is small (< ~5%) compared with the impact of hidden terminals and target distance from the receiver. Therefore simulation results should not change significantly if regional entry was introduced in the simulation.
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